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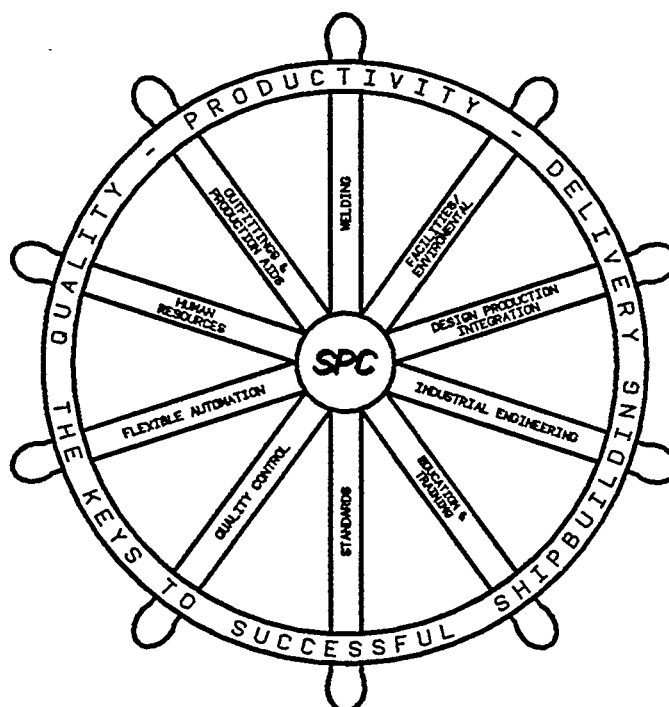
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**THE NATIONAL SHIPBUILDING
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A Plan for Identifying A More Producible Structure for Tankers

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ABSTRACT

This paper addresses a plan for research and development leading to alternative structural system concepts for tankers. These should decrease labor requirements in design, fabrication and outfitting phases. The plan begins with addressing those aspects of concurrent engineering which, when applied, will result in the optimum characteristics with least cost from both the builders' and owners' perspectives. The next steps address identifying characteristics of structural systems which offer promise, and the assembly of these into alternative structural system concepts based on their apparent potential for improved producibility. Then, the application of the systems to specific vessels and methods to evaluate the improved producibility are considered.

INTRODUCTION

Overview

It is generally acknowledged that the cost of acquiring ships from U.S. shipyards is higher than from foreign shipyards, particularly from the Far East, Southern Europe and Brazil. The reasons have been vigorously debated; government subsidy and availability of favorable financing in these overseas locations have been identified as very serious potential reasons for the differences. These are generally not within the control of the shipbuilding community. However, it has also been acknowledged that there are other significant differences of a more technical nature which will have a substantial impact including: labor hour requirements for design and construction; materials, equipment, and machinery costs; shipbuilding practices and facilities; long lead delivery times; stringency of standards; contractual processes; and institutional constraints.

During the last twenty years the shipyards, various agencies of the government and the Society of Naval Architects and Marine Engineers (SNAME) have tried to address the matter and improve producibility. The U.S. shipyards have acknowledged the advancement of

Japanese shipbuilding techniques, and, along with the U.S. Maritime Administration (MARAD), they have imported technology from innovators like IHI, who has transferred information to Bath Iron Works, Newport News Shipbuilding, Ingalls Shipbuilding, Avondale Shipyards, and others. MARAD and later SNAME have sponsored the National Shipbuilding Research Program (NSRP), which supports extensive and varied research in shipbuilding technology from design through delivery. Yet, a significant gap still appears to be present between the U.S. and major world shipbuilders. Are the reasons a lack of innovation, sufficient effort, facilities enhancement or application?

The time required for the construction of a vessel has been identified as having a major impact on vessel cost. Reported delivery times in foreign shipyards are considerably less than U. S. shipyards. The reasons for this must be largely tied to the nature of the structure being manufactured, and to the degree it facilitates fabrication and installation of outfit prior to erection on the building docks. The design phase and its integration with construction has a significant influence on achieving this goal. The purpose of this plan is to aim at the heart of those matters which can make a difference and are in the shipbuilder's control.

The outline of the plan presented herein was developed in the course of preparing a proposal in response to the U. S. Coast Guard (USCG) Ship Structure Committee solicitation for "Hull Structural Concepts for Improved Producibility (SR-1351)," which has subsequently been awarded to M. Rosenblatt & Son, Inc.

Background

Although the recent upturn in international shipbuilding has currently stalled, it is acknowledged that the world's aging tanker fleet must be replaced in the years to come. This will provide a magnificent opportunity to revitalize shipbuilding in the U.S. Furthermore, the passage of the Oil Pollution Act of 1990 (OPA '90) in the U.S. has resulted in new tanker arrangements to be provided, specifically double hulls,

and this allows significant latitude for the development of designs with innovative enhancement for producibility. These could give the developer a significant advantage over the competition.

The time is right for the U.S. shipbuilding industry to address this potentially crucial crossroad. An approach may be to "develop alternative structural system concepts" for potentially desirable tanker sizes, 40,000 and 100,000 DWT. These should result in decreased labor requirements in the design, construction, and outfitting phases of a shipbuilding program, as well as provide for low cost maintenance during the life of the vessels. Addressing these types and sizes of vessels will provide information to shipbuilders for use in the upcoming boom for rebuilding the world fleet.

Decreased labor requirements will obviously lead to reductions in the time and cost of building ships. By introducing superior alternative structural systems into the construction program, possibly together with other innovative technologies, significant improvements will be obtained in the fabrication, assembly and erection time schedules. As a result, an environment will be created for the U.S. shipyards to favorably compete with European and Far Eastern shipyards for world ship construction orders.

It is noted that the NSRP, more recently under SNAME sponsorship and U.S. Navy funding, has long dedicated its efforts to investigate methods of improving producibility in shipbuilding. Some of the projects that are currently included in the NSRP'S scope are closely related to this matter, e.g., Project 4-93-6, which calls for the development of a design manual for producibility of hull foundations, and 4-93-2, which is directed at reducing ship construction time and cost in U.S. shipyards. Other NSRP projects are also circumstantially related to the subject considered herein. It will be extremely important to summarize the massive NSRP research and development program and build upon it, rather than risk re-investigating some of the same matters.

Without a doubt, constraints may be imposed on the considerations due to the current nature of the existing shipyards and their facilities. Yet further involvement of U.S. shipyards in commercial shipbuilding must take place within the next few years; otherwise, it may be too late. Consequently, any alternative approach must not rely on massive facilities enhancements.

In all this, the shipowner must not be forgotten. New ships must be reliable and maintainable, or the shipowner, the customer, may not be willing to purchase a vessel. The automobile industry has established a precedent where a dissatisfied customer

has turned to foreign sources for a major portion of the product.

Summary

The meeting of the objectives presented herein lie at the heart of the future of shipbuilding in the U.S. To be successful the plan must concentrate on the structural systems and their impact on design, fabrication, outfitting and maintenance. It should not dwell on policy, major facilities enhancement or futuristic scenarios.

The output should consist of one or more alternative primary and secondary structural system concepts for each ship which demonstrate the ability to achieve reduced labor hours for contract and detail design, construction and improved maintainability. The installation of ship's outfit, equipment and piping in subassemblies prior to erection on the ways of building docks must be incorporated in the strategies, as this has been shown to be a significant contribution to increased producibility.

The sections which follow address the principal components of the plan: use of concurrent engineering principles; identification of potentially advantageous structural elements and alternative systems; identification of the sample applications which should identify their merits; and evaluations of alternative system concepts needed for comparison purposes.

CONCURRENT ENGINEERING REQUIREMENTS

General

Concurrent engineering is an approach to developing a product which seeks to integrate design, production and user requirements from the outset, to arrive at the optimum solution in the most direct manner. The objective for the matter at hand should be the definition of those characteristics of concurrent engineering which, when applied to tanker structural design, will result in producing the optimum characteristics with least cost.

At a point in time when all possible alternative structural concepts will be considered to evaluate their pertinence, the level of design can only be conceptual/preliminary. A recent report discusses introducing the ship construction method and sequence earlier into the design process, with emphasis on preliminary build strategy, subdivision of the hull into erection units and modules, and advance planning for the development of work instruction packages during the detail design (1). The interests of the shipowner has been incorporated as well. By expanding on this

approach, a concurrent engineering philosophy and its characteristics for this project can readily be established.

Philosophy of Construction

The objective of both the shipyard and owner should be identical in the delivery of a ship. However, their concerns along the way will be different.

Shipowners are principally concerned with obtaining a vessel that will meet their performance requirements at a favorable price and schedule. They may tend to be unconcerned with the distinction between the design phases, but will seek to understand the nature of not only the principal design characteristics, but the intended detail of the construction and character of the equipment provided, in particular as to how it impacts reliability and maintainability. As an additional concern, OPA '90 has placed a significant amount of liability for spills on the shipowners, and it can be expected their concern for risk, reliability and safety will be especially acute.

Shipyards are concerned with the design and construction details of the vessel once a contract has been signed. Theoretically, a shipyard is free to incorporate the production attributes of the organization into the design process at any stage. As personnel most experienced in production may not always be associated with the design departments, successful integration of production into design must involve a coordination of disciplines, which does not always occur.

Design, construction and shipowner requirements should be properly integrated to achieve the most desirable structural alternatives at lowest cost.

STRUCTURAL ELEMENTS

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The characteristics of the structural elements which can be utilized in assembling structural systems for double hull tankers should be identified first. These will include tanker structural concepts, individual structural components, structural standards, and processes. This can be achieved through the identification of structural elements utilized in the past, proposed concepts, variations suggested by new and relatively modest fabrication equipment, and characteristics suggested for possible reduction of potential oil pollution.

Overall Considerations

Tank vessels have been traditionally designed as single skinned hulls. Depending on the size of the vessel, longitudinal bulkheads are often present; and the overwhelming majority of single skinned designs are longitudinally framed (Figure 1). As a result of major oil spills and the resulting damage to the environment, the U.S. Congress has mandated in the OPA '90 the use of double skinned tanker designs (Figure 2) as an effective means to protect the ocean environment from potentially devastating oil pollution. Since then, a number of alternative generic configurations have emerged as well, most prominently, the mid-deck design (Figure 3), and are being considered by the international community, although not permitted by OPA '90. All of the new designs are aimed at achieving the same objective, i.e., to reduce the likelihood of oil spill and to reduce the amount of outflow in the event of hull puncture.

The function of a tank vessel's structural system may be viewed from the standpoints of normal operation and casualty operation. In providing adequate resistance for normal operations, the objective in structural design is to maintain structural integrity of the hull girder, of bulkheads, decks, plating, stiffeners and details. Other considerations relate to vessel size, complexity and heaviness of the structure, producibility, and maintainability. In terms of casualty operations, the objective is to maintain vessel integrity and to protect cargo, or, conversely, to protect the environment from oil pollution in case of a casualty. In this case, the primary considerations should encompass:

1. Resistance to fire and explosion damage and its containment;
2. Resistance to collision and grounding damage;
3. Containment of petroleum outflow if damage does occur; and
4. Maintenance of sufficient residual strength after damage in order to permit salvage and rescue operation, and to minimize further damage and spilling of oil.

Tanker structure is characterized by structural arrangements consisting of a number of elements oriented in repetitive patterns. Examples are the traditional transverse system consisting of transverse frames supported by girders and bulkheads, and the longitudinal system consisting of shell longitudinal

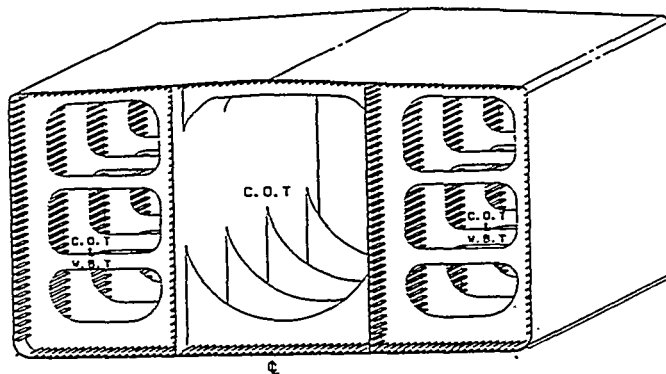


Figure 1: Single Skinned Tanker

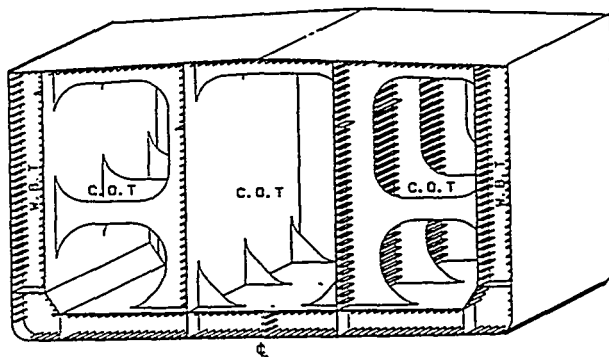


Figure 2: Double Hull Tanker

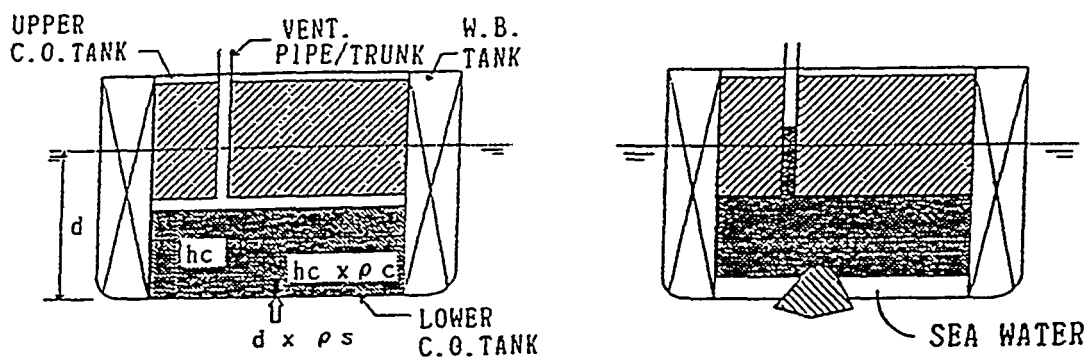


Figure 3: Mid-Deck Tanker

supported by web frames. These have been incorporated in most tanker construction to date.

In recent times unidirectional double hull structural systems have received attention from the commercial community (2). Specifically, this hull structural system uses a double hull structure supported between transverse bulkheads by a series of longitudinal girders between the hull skins (Figure 4). structural simplification is significant with intersections between the longitudinal and transverse members reduced to a minimum. Other new concepts have been developed as well, such as the dished shell plate system (3), wherein the added strength due to the curvature in shell and bulkhead plate supplants the need for stiffeners.

- Longitudinal girders
- Deck
- Transverse bulkheads
- Longitudinal bulkheads
- Material

Furthermore, and although not currently a specific or impending regulatory requirement, alternative structural systems can provide varying amounts of protection of oil outflow during collision. A theoretical estimate of energy absorption during collision and prior to cargo tank penetration is shown in Table I (4). The results indicate a wide range of energy absorption potential for the specific embedments considered.

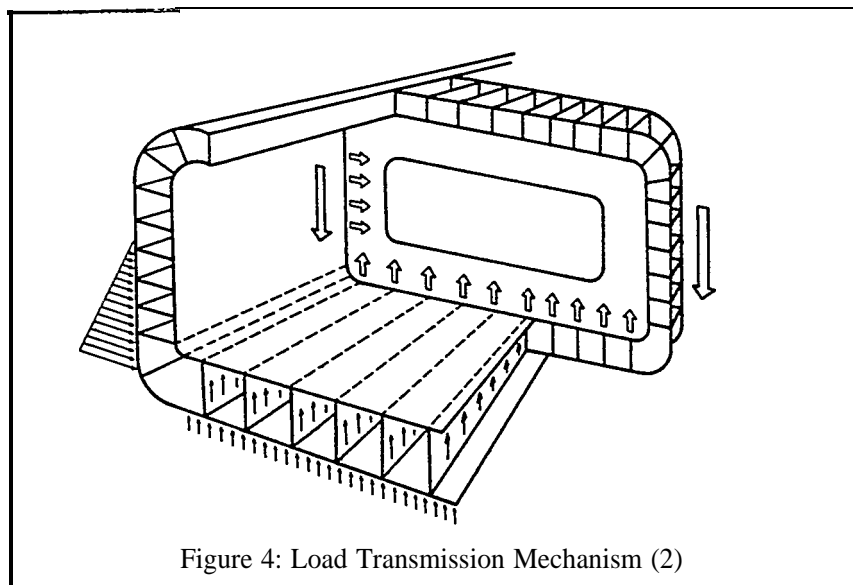


Figure 4: Load Transmission Mechanism (2)

As an example, the structural elements representative of conventional and unidirectional systems are as follows:

Conventional Single and Double Hulls

- Shell (inner and outer)
- Side and bottom stiffeners
- Web frames
- Brackets
- Deck
- Transverse bulkheads
- Longitudinal bulkheads
- Transverse floors
- Material

Unidirectional Double Hull

- Shell (inner and outer)

It is important, as well, to consider the philosophy behind and characteristics of the structure as significant production improvements may be possible. Hofmann et al (5) have shown that for the longitudinally framed T-AO 187 class fleet oiler the following producibility features result in savings:

- maximized areas of flat plate;
- maximized areas of single curvature, for remaining shell plating;
- increased frame spacing and reduced numbers of piece parts in structural assemblies;
- standardized brackets and web frames, and use of bilge brackets in lieu of longitudinal stringers in the bilge turn area and
- carefully arranged erection joints.

Vessel	Single Skin	Double Skin	Unidirectional	Single Skin
DWT	138,180	138,180	138,180	138,180
Depth m (ft)	19.4 (63.5)	19.4 (63.5)	19.4 (63.5)	21.0 (68.9)
Stiff Spcg m (ft)	0.91 (3.0)	0.91 (3.0)	0.91 (3.0)	Unknown
Web Spcg m (ft)	3.81 (12.5)	3.81 (12.5)	N/A	Unknown
Bhd Spcg m (ft)	15.24 (50.0)	15.24 (50.0)	15.24 (50.0)	Unknown
Energy/m Kjoules/m	15,700	28,400	60,090	18,360

Table I: Comparison of Sideshell Energy Absorption (Per Meter of Depth)

Structural Components (6):

A number of structural components can be identified which are new or have not found wide applications in the past but offer potential advantage. These are enumerated below:

Tapered Plating:

1. In 60's and 70's US Steel claimed the ability to produce tapered plates. Longitudinal tapering of plate has been accomplished in Germany and France (7).
2. If tapered plates were used for sheer and stringer stakes, for instance, weight, welding, and edge preparation could be reduced.
3. Fatigue cracking might be reduced because of smoothness of transition.
4. Ship resistance would be improved (slightly).
5. Notching in supporting structure would be eliminated.
6. The disadvantages are added cost, lack of standardized sizes (width, thickness, taper all

vary), and material handling and storage are more complex. Repair in service may present difficulties.

Corrugated, Swedged, and Dished Plates:

1. Used to eliminate stiffeners.
2. Increases buckling resistance over flat plates.
3. Saves on welding and residual stresses.
4. Would have to be corrugated, swedged, and dished in shipyard.
5. Storage and handling problems.

Fabricated stiffeners and girders:

1. High strength flanges with ordinary strength webs.
2. Ability to produce high strength structural w/o special heat treatment after fabrication.
3. Save weight and cost.

Coiled Plate: for thinner plating - can reduce cost.

Lapped Joints: For non-critical structures - saves fabrication and erection costs. However, these have been a source of corrosion and fatigue in some applications.

Formed Hopper Knuckle:

1. Eliminates fabrication complexities at outboard bottom corner edges of double hull cargo tankers.
2. Eliminates weld line at this location as a potential source of failure and unreliability.

Structural Standards (6,8)

The introduction of structural standards or standardized designs (9) offers the opportunity for dedicated fabrication techniques and mass production of parts, all with the result of lower construction prices. Reliability should be expected to be enhanced as well. Examples could be in the following areas:

- o stiffener spacing
- o stiffener sizes
- o structural details
- o equipment and foundations
- o double skin separation
- o materials used - strength, toughness, fatigue strength
- o aft end design - Eng Rm
- o fwd end design - mooring etc.
- o transition: double skin to single skin (structural arrangement)
- o accuracy

Miscellaneous Inputs (6,8)

Process or peripheral considerations can seriously affect the characteristics of fabrication, and need to be addressed as well. These could include:

Line Heating: Accurate economical and efficient plate bending.

Robotics: Used in welding, painting and paint touch-up, and in inspection.

Developable Surfaces: Structural performance vs. producibility - Use on inner hull and some areas of outer hull.

Welding - develop to improve fatigue performance and increase automation:

- o weld contour
- o weld heat affected zone
- o one-sided welds
- o reduced built-in stresses

Heat Forming:

Transition from double to single-skin:

- o forward end of cargo box
- o aft end, at some location in engine room, such as aft of settling tanks

Numerically Controlled (NC) cut hull penetrations.

Statistical Accuracy Control: The efficiency of mechanization and automation can be enhanced with better accuracy (10). Examples include numerical simulation of heat deformation in burning, welding and bending; mechanization to reduce human error; and three-dimensional measurement of blocks during assembly and at the erection site.

Modular Construction:

- o Block and zone definition.
- o Work station/Zone information (11).

ALTERNATIVE STRUCTURAL SYSTEM CONCEPTS

General

The structural elements as discussed in the previous section should then be synthesized into alternative structural system concepts based on their apparent potential for improved producibility. These would then become the candidate alternative system concepts to be utilized in further considerations.

The nature of the alternative structural concepts will be that their principal characteristics are sufficient to establish the entire structural concept for a tanker. That is, they are to consider shell, inner hull, shell stiffening, subdivision bulkheads, and primary hull structure. Some aspects of the alternative concepts may be similar to those already utilized in tanker construction, as these have proven effective. On the other hand, even previously adopted concepts may offer opportunity for optimization as, for example, in the

number of structural pieces or processes employed in fabricating them.

Initial Examples

The types of alternative concepts that may result are described in the following examples:

- o Dished plate hull - The increased strength of plating exhibiting curvature is utilized to eliminate stiffeners. Standard unit sizes result in a building block approach to constructing various hull sizes.
- o Longitudinal framing with formed hopper side comer and corrugated bulkheads - Longitudinal stiffening on shell plating with formed structure for difficult to manufacture and potentially high stress prone areas.
- o Unidirectional stiffening supporting inner and outer shells and corrugated transverse bulkheads - Inner and outer shell stiffening in a single direction along entire hull. Transverse bulkheads supported by stools inboard of the double hull structure.
- o Unidirectional framing on ship sides and conventional double skin firming for deck and bottom as ship sides are more prone to fatigue failures than deck and bottom.

Numerous other alternative concepts and their variants should be synthesized.

Preliminary Producibility Evaluation

In order to identify the potential for improved producibility for each of the alternative concepts prior to their selection for comprehensive evaluation, a subjective analysis should be undertaken at this time.

The characteristics enumerated below have been suggested as an approach to examining a design with regard to Design/Engineering for production for new or unusual designs, or for shipyards without sufficient information to formulate and analyze designs using a formal, quantitative model for comparison (12). It is suggested that alternative designs be examined in the same manner and compared to known baseline designs.

1. Number of unique parts
2. Total number of parts

3. Number, type and position of joints

4. Complexity of design:

- o simple measuring
- o simple manual layout
- o complicated manual layout
- o CAD/CAM applicability
- o required manual processing
- o required machine processing

5. Producibility aspects:

- o self-aligning and supporting
- o need for jigs and fixtures
- o work position
- o number of physical turns/moves before completion
- o aids in dimensional control
- o space access and staging
- o standardization
- o number of compartments to be entered to complete work

The number of parts has already been mentioned as an important measure. The type and position of joints for the double skin unit is a critical aspect, as the distance between the inner and outer skins affects access. The adoption of unidirectional stiffeners only between the double skin could allow for a robotic welding system. Innovative construction scenarios will have to be adopted to keep the double skin from negatively affecting the work procedures and work environment, to minimize the number of physical turns/moves, to provide space access and staging and to minimize the number of compartments to be entered to complete work. On the other hand, as the double skin sideshell structure is more rigid and self supporting than the single skin, units of the double skin could provide for easier alignment than single skin sideshell structure, resulting in a reduction in the need for jigs, fixtures and staging.

As a final consideration, special features of the concepts which will enhance pre-outfitting and utilization of machinery modules should be highlighted.

Design Information

The results of these considerations should be a series of alternative structural system concepts for tankers. Each should be described by:

- o An arrangement sketch,
- o Preliminary producibility evaluation,
- o Highlight of principal features which can be tailored to a specific design, and

- o Degree of adaptability to unit construction, pre-outfitting and incorporation of machinery modules.

APPLICATION TO SPECIFIC VESSELS

General

The next step should be the application of each alternative structural system concept to specific vessel sizes deemed to be marketable.

First, a hull form, arrangements, and machinery representative of the size to be considered should be identified. The producibility impacts of these, as they affect structure, should be considered as well. Then, a midship section should be synthesized for each structural system concept considered.

The production inputs, including shipbuilding policy, facility dimensions and capacities, and interim product types, should be selected in a manner that can be accommodated by the shipyards. As an example, crane lifting capacity may have to be limited.

The results for each ship and structural system concept will include:

Design

- o General arrangement sketch,
- o Midship section,
- o Scantling plan sketch [longitudinal extent of structure], and
- o Hull form sketch.

Production

- o Outline build strategy including pre-outfitting,
- o Preliminary block breakdown,
- o Zone identification,
- o Material preferences, and
- o Fabrication preferences.

ESTIMATES FOR ALTERNATIVE SYSTEM CONCEPTS

In order to compare the candidates according to the degree they lend to an improvement in producibility, estimates should be prepared for the following characteristics which are known to be measures of producibility and reasonableness of design

- o Contract and detail design manhours
- o Construction manhours

- o Schedule - contract signing to delivery
- o Weight of structure

The design manhour estimates should be based on the same midbody portion of the hull for which weight will be determined. The estimate will be dependent upon the required number of drawings and calculations adjusted to reflect the number of details required, repetitiveness of structural arrangements, unit similarity, pre-outfitting, and incorporation of machinery modules. The design requirements for a more typical tanker should be included as well, for comparison purposes.

The construction manhour estimate and schedule should consider:

- o Amount of welding,
- o Type and number of frames, and stiffeners,
- o Number of unique parts,
- o Total number of parts,
- o Number, type and position of joints,
- o Self-alignment and support,
- o Need for jigs and fixtures,
- o Work position,
- o Number of physical turns/moves before completion,
- o Dimensional control,
- o Space access and staging,
- o Standardization,
- o Number of compartments to be entered to complete work,
- o Degree to which pre-outfitting and machinery/piping package units can be accommodated,
- o Accuracy control.

The schedule or time line for design and construction will be an essential consideration. Foreign shipyards that are building tankers are now working on schedules from 18 months to 24 months from contract signing to delivery. Examples of past and recent time lines from start of fabrication to delivery are shown in (Figure 5). It should be expected that reduced schedule times will be accompanied by reduced manhours. The impact on schedule of series construction of ships must be quantified as well.

The weight estimate should be a direct take-off from the midship section and scantling plan sketch, and summarized in an appropriate format. The weight of a more typical tanker structure should be provided as well, for comparison purposes.

In an effort to simplify the producibility investigation, yet keep it meaningful, a portion of the

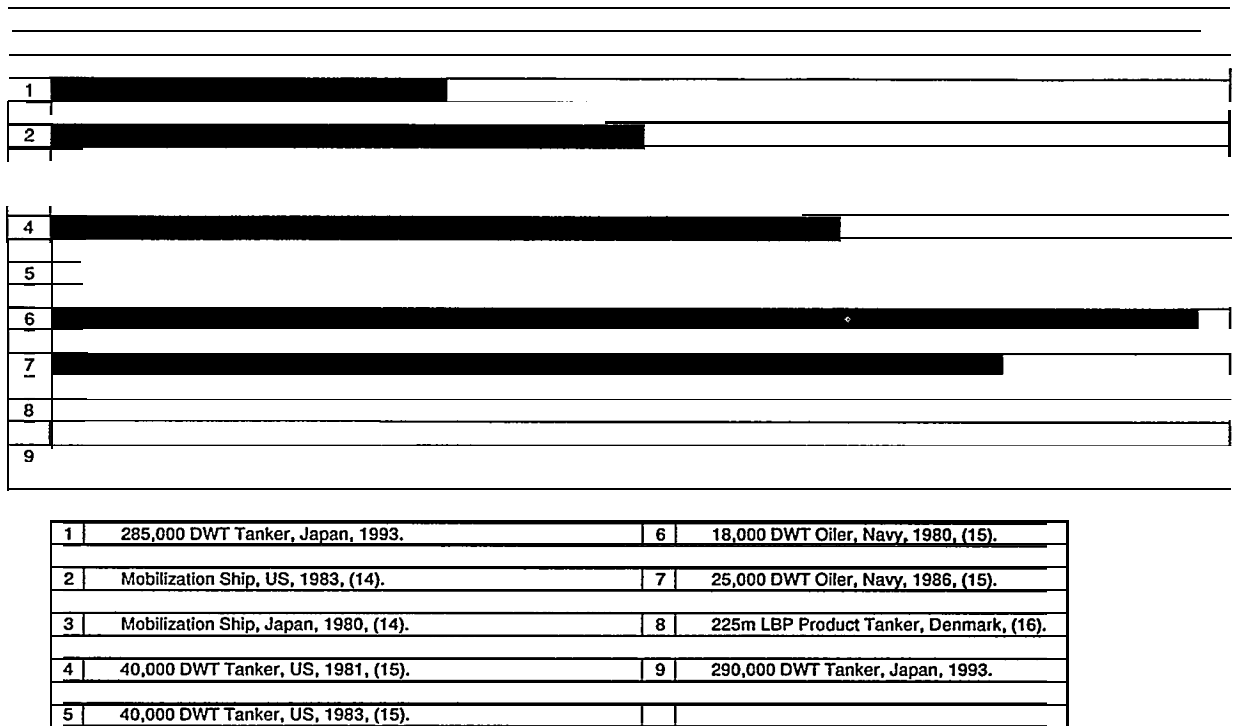


Figure 5: Fabrication to Delivery Time Lines

hull midbody from keel to main deck, and from one major transverse bulkhead to the next, with structural components as represented in the midship section drawing, should be utilized. This length of hull can then be broken down into all its component plate and stiffener pieces, including brackets and chocks. For each of these pieces the weight, area, and various linear measures of cutting, edge preparation, and welding can be tabulated for each of the alternatives as well.

EVALUATION OF CONCEPTS

The alternative structural system concepts for each of the tanker designs should then be compared with regard to the degree they lend themselves to improved producibility.

Recently, two methods for evaluating the producibility of ship designs and/or ship design alternatives have been developed under the sponsorship of Panel SP-4, Design/Production Engineering, of the SNAME SPC/NSRP (13). One provides quantitative results in manhours or dollars; the other provides relative results based on weighting factors developed for specific ship projects, and the design phase during which the alternatives are being considered. This latter

approach includes evaluation of numerous parameters, including cost, performance, schedule and risk.

SUMMARY

The potential for significant worldwide construction of tankers is near. The time is right for a systematic evaluation of structural concepts for tankers which are advantageous for U.S. shipyards. This scenario represents a unique opportunity to apply the significant knowledge gained through the SNAME SPC/NSRP over the years to a specific ship type.

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